DEPARTMENT OF COMMERCE
BUREAU OF FISHERIES
HENRY O'MALLEY, Commissioner

AQUATIC PLANTS IN POND CULTURE

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U. S. Bureau of Fisheries

APPENDIX II TO THE REPORT OF THE U. S. COMMISSIONER OF FISHERIES FOR 1923

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POND CULTURE AND ITS APPLICATION.

Among the fresh-water fishes most desirable for food purposes and for sport-fishing there are certain species, such as the basses, crappies, sunfishes, and catfishes, that are not susceptible to manipulation for the taking and impregnation of their eggs, but must be allowed to mate and select nests, on which the spawn is deposited, fertilized, and hatched in the natural way. For the cultivation of these species, therefore, it is necessary to provide surroundings fulfilling their requirements, and at the same time permitting control of the fish, which purpose is accomplished by the maintenance of natural or artificial ponds. These ponds are stocked with the maximum number of adult fish, and the young hatch in numbers abnormal for the volume of water in which they are contained, there to be reared for a few weeks or months and then distributed to other waters as desired. The pond itself affords sustenance to

[1] Appendix II to the Report of the United States Commissioner of Fisheries for 1923. B. F. Doc. 948. The first edition of this paper, Bureau of Fisheries Document No. 643, was published in 1909, and various reprints have been issued.

the young, and therefore the pond is the direct object of attention in order to produce the maximum number of fish. Fish culture under these conditions is consequently intensive pond culture, and in the United States the term "pond culture" distinguishes this branch of fish culture from the propagation of all fishes whose eggs can be expelled and fertilized artificially or which are incubated in hatching houses by the use of special apparatus and equipment. The species to which it is applied are chiefly the black basses, crappies, sunfishes, and catfishes.

The propagation of the Salmonidæ, notably the trouts, approaches pond culture in the fact that several species are often reared in ponds, whereas the other fishes hatched in special equipment are usually distributed as fry as soon as the yolk sac is absorbed. However, although the cultivation of the trouts in this country may require ponds in which to rear the young, the different service the ponds perform and the different management required place American trout-rearing methods outside the proper definition of pond culture.[2] In Europe the case is not wholly similar; although in a few instances American methods have been adopted, the term "pond culture" usually embraces the rearing of trout by much the same methods as are in the United States pursued only with fishes that can not be artificially spawned; that is, the young trout may not be fed artificially but often subsist in large part upon the natural food supply induced by culture of the ponds.

IMPORTANCE OF AQUATIC PLANTS IN POND CULTURE.

Since the young of the species of fishes to which pond culture is applied in the United States can not be successfully confined in the troughs or small ponds of the American trout breeder and do not accept artificial food, they must depend for sustenance upon minute forms of animal life found in the waters and upon one another. At a very tender age they develop cannibalistic tendencies, and even where there is apparently an abundance of natural food they may reduce their own numbers 60 to 80 per cent within a month or six weeks from the time of hatching. It is therefore necessary in pond culture to provide not only sufficient natural food to satisfy the physiological requirements of the young fish, but, so far as possible, an abundance that will divert them from the tendency to devour one another.

[2] It may not be amiss here to point out the distinction between trout culture by American methods and pond culture proper by reference to the procedure and the conditions at an American trout hatchery. Trout are not dependent upon natural food and do not require a natural environment. It is customary to rear them in wooden troughs or in small rectangular ponds of earth, wood, or concrete, through which there is a constant flow of water containing no visible plant or animal life. The water supply may come directly from a spring or from an artesian well. At many of the most successful commercial trout establishments in the United States the troughs and rearing ponds are supplied with water from artesian wells from 25 to 100 feet in depth. As the daily feeding of a large number of fish in a confined area necessitates frequent cleaning, any seeds or spores of vegetation introduced by the water supply have little or no opportunity to obtain a foothold. The trout fry will eat artificial food from the time the yolk sac has been absorbed, and by a judicious arrangement of troughs, tanks, or small ponds the trout raiser can maintain a very large number of fish within a comparatively small compass until they are of satisfactory size for distribution or for market. His dependence is artificial food or the artificial introduction of natural food, and without these means he would be powerless to conduct operations on an extensive scale. In American trout culture aquatic vegetation, so essential in pond culture, is but a negative factor.

Through the necessity for natural food, then, comes the primary importance of aquatic plants in pond culture. All animal life is dependent, directly or indirectly, upon plant life, the minute forms as well as many of the larger feeding directly upon plants, and the herbivorous species in turn serving as food for the carnivorous. In the beginning the young fishes feed upon water lice, nymph larvæ, and other minute forms. As they develop in growth they feed upon small crustaceans, insect larvæ, and other forms that are not ordinarily abundant except in an environment with abundant vegetation. Aquatic plants are therefore the food-producing agency in pond culture and are accordingly indispensable. It is also obvious that by a judicious selection of plants the quantity of food can be maintained at the maximum, with corresponding results in the production of young fish.

It is the consensus of opinion among pond culturists that plants are essential also for the proper aeration of the water. At a trout hatchery the fish are supplied with the necessary air by means of a constant flow of water; in pond culture the volume of water supply is often little, if any, more than enough to compensate for evaporation and leakage, and the oxygenation from this source is limited. The balanced aquarium is a well-recognized illustration of the value of plants as oxygenators. Although there are many factors entering into the aeration of the waters at a pond-culture station that do not apply to the balanced aquarium, and it may be assumed that the larger the body of water the more must other factors than those of the balanced aquarium be considered, there can be no doubt as to the rôle of vegetation in the aeration of shallow ponds of limited area.

It is perhaps superfluous to add that submerged plants bind the bottom soil together, thus acting as a deterrent to turbidity from that source; and that plants doubtless facilitate clarification when the water of a pond has become turbid with surface drainage after a rain or from other external causes of a temporary character. As an evidence of this the numerous reservoirs or "tanks" in the West, which are devoid of vegetation and in which the water is constantly roiled, may be cited. It is possible that in some instances the absence of vegetation is due to the constantly roily water, a condition elsewhere referred to; but control tests in aquaria demonstrate that in an aquarium containing Cabomba the water is clarified much more quickly than in one in which there is no vegetation.

Some other advantages of aquatic plants that are of more or less importance may be mentioned, such as shade, shelter from predacious birds, and refuges for the smaller fishes from the larger ones and from each other. The ornamental feature of some plants in some places is of minor importance from the viewpoint of the fish-culturist, but all of these have been given consideration.

OBJECTIONABLE ASPECTS OF POND VEGETATION.

Notwithstanding their essential importance in fishponds, however, and the careful effort requisite to the securing of suitable vegetation, in one aspect nearly all aquatic plants are to the pond culturist wholly a nuisance and a necessary evil. The seining of the ponds,

to obtain the young fish for distribution to waters they are intended to stock, or for other purposes, can not be accomplished while thick plant growth is present to entangle the fish and interfere with the operation of the seine, and there is thus a periodical necessity of clearing away or at least reducing all gross vegetation. This process is laborious and expensive; the cost of operating a pond-culture station is, in fact, largely the cost of this periodic clearance of the ponds and varies with the characteristics of the predominating species of plants. Methods in practice at several stations are described in a later portion of this paper.

Particular kinds of vegetation may be objectionable also in specific ways other than with reference to the difficulties of removal at seining time. Large-leaved plants may offer too much shade to permit other plants and the requisite animal life to thrive; plants of persistent growth may take possession of the ponds and crowd out species more desirable; or plants not in themselves objectionable may not be desired because other obtainable plants are more desirable for the same qualities. The question becomes one of control. Wherever there is soil bottom vegetation is voluntary, springing up immediately even in artificial ponds, and any attempt to prevent the entrance by natural agencies of water plants common to a region is fraught with much the same difficulties that are encountered in the attempted exclusion of weeds from a garden. It remains to secure the balance that will bring the conditions nearest to the ideal.

AQUATIC PLANTS AT THE POND-CULTURE STATIONS OF THE BUREAU OF FISHERIES.

With its wide geographic range the Government work in pond culture naturally embraces a variety of conditions and affords interesting and profitable comparisons. The climate, the quality and temperature of the water, the character of the soil, as well as other factors, make the management of each pond-culture station a separate problem. The inevitable dependence upon a natural food supply for the young fish, however, concentrates the efforts in such work about the great factor of vegetation and, next to water supply, makes the selection and control of aquatic plants in ponds the most important question with which the pond culturist has to contend. The popularity of the basses, crappies, and sunfishes, moreover, and the feasibility of increasing their numbers by cultivation make pond culture a subject of especial interest to people everywhere in the United States, and the Bureau of Fisheries is constantly receiving inquiries and requests for information. The following notes are therefore thought to have interest and value not only to the professional fish-culturist but to the public generally. They represent efforts to collect specimens of all the aquatic plants found at the various pond-culture stations of the bureau, with observations of the respective superintendents as to the particular value of the desirable species and the objectionable characters of the undesirable. It is hoped thus to aid in determining the relative value of each, or at least to afford data that will be useful in future work, at the same time emphasizing the fact that present knowledge of the subject is all too limited. These notes are not based upon biological or other scientific investigation, but are gained from the observations and experience of prac-

tical fish-culturists. They are presented, moreover, as pertaining only to the particular field of pond culture conducted by the bureau. Their application beyond this is yet to be determined.

It may be assumed that all aquatic plants harbor a certain amount of minute animal life. In the following descriptions, therefore, the term "food producer" is applied to plants conspicuous for the large quantity of small animal forms living or breeding thereon. The term "oxygenator" is applied to plants believed to be especially useful in keeping water in a proper condition by throwing off oxygen. The word "shelter" is applied to plants that afford the small fish a hiding place and protection from the large ones and serve as an aid to the prevention of cannibalism among the fishes. The term "ornamental" is used to designate those plants that extend above the surface and beautify the ponds. The depth of water in which the plants are found as here mentioned applies to the ponds of the respective stations in question. It is recognized that some of the plants thrive in much deeper ponds and lakes. In most instances the plants described under the various station heads are indigenous, having appeared voluntarily. There are no records to show to what extent plants have been introduced, but undoubtedly some of the more desirable plants have been introduced, largely through transfer from one station to another.

Common names of the plants are given, but as these are often of restricted local application the botanical nomenclature also is used, and for more ready identification figures have been inserted for almost every species. All but one of the cuts are copied from Britton and Brown's Illustrated Flora of North America. The figure of Chara is taken from the Text Book of Botany by Strasburger, Noll, Schenk, and Schimper. The geographical range of the respective species likewise is taken from these authorities.

For the identification of a large number of these plants the bureau is indebted to Messrs. J. N. Rose and G. H. Shull, of the United States National Herbarium, Smithsonian Institution, and also to the division of botany, Department of Agriculture.

COLD SPRINGS, GA.

At this station the water supply comes from a large spring, and the maximum water temperature is about 82° F. The water contains only a trace of lime, and as a result some difficulty has been experienced in stocking the ponds with aquatic plants, but efforts in this direction have resulted as follows, as reported by a former superintendent:

For ponds with fairly fertile bottoms with an admixture of muck and clay, the foxtail (*Myriophyllum spicatum*) excels all other species. It makes an ideal growth, affords abundant cover for the fish and for the minute life upon which the fish feed, and is apparently a good oxygenator. At the same time it offers but little obstruction to seining operations owing to its slender, feathery growth. Even for ponds having rich muck bottom it has been found most satisfactory, though in such ponds considerable work is required to remove it when preparing for seining.

For ponds with sterile bottoms of clay, sand, or gravel, where foxtail will not thrive, parrot-feather (*Myriophyllum proserpinacoides*)

attains an excellent growth and affords abundant lodgment for minute aquatic life and for the alevins; it also provides a sufficient amount of shade for the brood fish and suitable cover for their nesting places. Large-mouthed black bass seem to prefer the fibrous roots of these plants to all other nesting materials. Both plants disappear from the warmest parts of the ponds by midsummer and are replanted in the fall or following spring. Near the inflow, especially of ponds that are abundantly supplied with water, the plants thrive throughout the year. The parrot-feather is more susceptible to high temperatures than the foxtail. These two plants have proved so

FIG. 1.—Spiked water milfoil (*Myriophyllum spicatum*). Found in deep water, Newfoundland to Manitoba and the Northwest Territory, south to Florida, Iowa, Utah, and California. Commonly known as foxtail. (After Britton & Brown.)

FIG. 2.—Chilean water milfoil (*Myriophyllum proserpinacoides*). Native of Chile, introduced in various localities in the United States, where it is known chiefly as "parrot-feather." (After Britton & Brown.)

satisfactory at Cold Springs that there has seemed little occasion to experiment with other species.

FISH LAKES, WASHINGTON, D. C.

Although the Fish Lakes at Washington are no longer maintained, observations upon the characteristics of the plant life are valuable for purposes of comparison. The bottoms of the ponds were of dark fertile soil, the maximum water temperature was about 87° F., and the plant growth was extremely dense. Whether the elimination of some of this luxuriant growth would have resulted in a decrease in the production of young fish is theoretical. This station had been in operation nearly 30 years, and the lakes contained an unusually large number of plants when these observations were made.

The hornwort (*Ceratophyllum demersum*) is especially good as a food producer and shelter, is fairly good for shade, is a good oxygenator and a good aquarium plant, has little root anchorage, and will grow over hard bottom. It is found in 2 to 4 feet of water, extending to the surface, but not above it. It was considered the best plant in the ponds.

Fanwort (*Cabomba caroliniana*) also is especially good as a food producer, as a shelter, and for aquarium work, and is given second place. It is regarded as a good oxygenator and as fairly good for

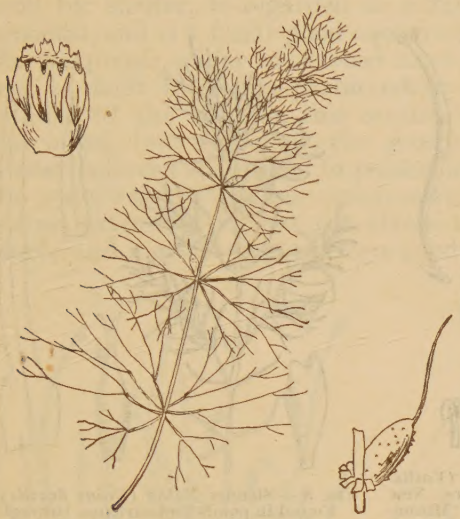

FIG. 3.—Hornwort (*Ceratophyllum demersum*). Found in ponds and slow streams throughout North America, except extreme north. (After Britton & Brown.)

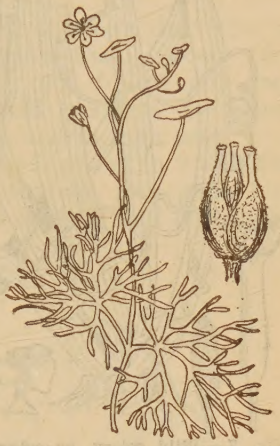

FIG. 4.—Fanwort (*Cabomba caroliniana*). Found in ponds and slow streams, southern Illinois to North Carolina, south to Florida and Texas. (After Britton & Brown.)

shade and, like the hornwort, has little root anchorage and will grow on hard bottom. It is found in 1 to 4 feet of water and extends nearly to the surface.

FIG. 5.—Curled-leaved pondweed (*Potamogeton crispus*). Found in fresh, brackish, or even salt water, Massachusetts to Pennsylvania and Virginia. Also in Europe. (After Britton & Brown.)

FIG. 6.—Leafy pondweed (*Potamogeton foliosus*). Niagara Falls to Michigan and California. (After Britton & Brown.)

The curled-leaved pondweed (*Potamogeton crispus*), a good food producer, oxygenator and aquarium plant, good for shelter, shade, and ornament, is one of the earliest plants to put forth shoots, and is

therefore valuable for early spawning fishes, such as the goldfish and carp. It is found in 2 to 5 feet of water, reaching to the surface.

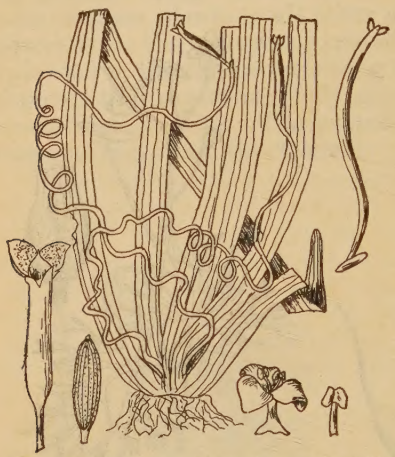

FIG. 7.—Wild celery, or eelgrass (*Vallisneria spiralis*). In quiet waters, New Brunswick to Florida, west to Minnesota, Iowa, and Texas. (After Britton & Brown.)

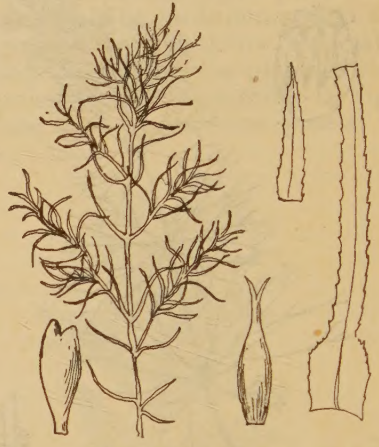

FIG. 8.—Slender Naias (*Naias flexilis*). Found in ponds and streams throughout nearly all North America. (After Britton & Brown.)

Another Potamogeton (*foliosus*), the leafy pondweed, also good as a food producer and oxygenator and for shelter, is found in 2 to 4 feet of water, extending to but not above the surface.

FIG. 9.—Waterweed (*Philotria canadensis*). Found nearly throughout North America, except extreme north. (After Britton & Brown.)

FIG. 10.—Water stargrass (*Heteranthera dubia*). Found in still water, Ontario to Oregon, south to Florida and Mexico. Also in Cuba. (After Britton & Brown.)

The wild celery, or eelgrass (*Vallisneria spiralis*), is found to be a good oxygenator and is a desirable plant because of its early growth. It is also good for shade and shelter and is an excellent

aquarium plant. It is found in 2 to 4 feet of water, extending to but not above the surface.

The slender naias (*Naias flexilis*), which is a good food producer, is good for shelter, is regarded as a fair oxygenator, is somewhat ornamental, and is a fairly good aquarium plant.

The six plants so far mentioned have been listed in the order of esteem as held by the superintendent of the Fish Lakes. The remainder of the list for this station does not follow any particular order, but, as before, the good or bad qualities the superintendent believed the plants to possess are noted in each case.

The waterweed (*Philotria canadensis*), which grows in 2 to 4 feet of water, extending to, but not above, the surface, is a good food producer and a good oxygenator, is good for shelter, and is valuable

FIG. 11.—Needle spike-rush (*Eleocharis acicularis*). Found in wet soil throughout North America, except in extreme north. Also in Europe and Asia. (After Britton & Brown.)

FIG. 12.—Tuberous white water lily (*Castalia tuberosa*). Lake Champlain west through Great Lakes to Michigan, south to Trenton, N. J., Meadeville, Pa., and eastern Nebraska. (After Britton & Brown.)

for its early growth. It also makes a good aquarium plant, but is dangerous in ponds, however, owing to its dense growth.

Water stargrass (*Heteranthera dubia*) has the same merits as the waterweed, being a good food producer, fair oxygenator, and excellent for the shelter it affords and for its early growth. It is found in water 1 inch to 4 feet deep.

The needle spikerush (*Eleocharis acicularis*) is of very little value except for its early growth. The fine, smooth culms are very easily cleaned by the large-mouthed black bass, which cast their spawn upon them.

One of the water lilies (*Castalia tuberosa*), which furnishes shade and shelter, is ornamental and of value because of its early growth. It serves as a good protection to young fish from predacious birds.

Floating heart (*Limnanthemum nymphæoides*), although but fairly good as a food producer, is excellent for shade, shelter, and ornament and is fairly hardy.

The fennel-leaved pondweed (*Potamogeton pectinatus*) is somewhat objectionable on account of its excessive growth. It is, however, a good food producer and a fair oxygenator and is fairly good for shelter. It is found in 1 to 4 feet of water.

The pickerel weed (*Pontederia cordata*), found in 6 to 12 feet of water, is not especially valuable in fish culture, although it has some merit for ornamental qualities, for shade, and for shelter. It is not thought to be a good oxygenator or food producer.

The two duckweeds (*Spirodela polyrhiza* and the more common *Lemna minor*) are not highly esteemed, though not especially objectionable. The larger form is quite ornamental, and both are of early growth. For fish-cultural purposes, however, their poor qualities as food producers and oxygenators make them insignificant.

The water clover (*Marsilea quadrifolia*) is excellent for shade and shelter and is ornamental and of early growth. It is objectionable

FIG. 13.—Water lily, or floating heart (*Limnanthemum nymphæoides*). Naturalized in ponds, District of Columbia. Native of Europe and Asia. (After Britton & Brown.)

FIG. 14.—Fennel-leaved pondweed (*Potamogeton pectinatus*). Found in fresh, brackish, or salt water, Cape Breton to British Columbia, south to Florida, Texas, and California. Also in Europe. (After Britton & Brown.)

in shallow ponds, however, completely covering the surface to a depth of about 2 feet.

At this station the limeweed (*Chara*) is valued as a food producer, harboring the small forms that are especially good as food for young fish, and as an oxygenator it is found remarkable. It is fairly good for shelter and as an aquarium plant.

The spatterdock (*Nymphæa advena*) is valued chiefly as an ornament and for the shade and shelter it affords. It is also of early growth, but it is a poor food producer on account of its long, smooth stems, which do not provide favorable breeding places for insect larvæ or other minute animal life. It is found in 1 to 4 feet of water.

The long-leaved pondweed (*Potamogeton lonchites*) does not rank with the two other Potamogetons mentioned here, being but fairly good in any of the important respects.

The water chestnut (*Trapa natans*), though fairly good as a food producer and for shelter, shade, and ornament, is of negative value in fish culture.

FIG. 15.—Pickerel weed (*Pontederia cordata*). Borders of ponds and streams, Nova Scotia to Minnesota, south to Florida and Texas. (After Britton & Brown.)

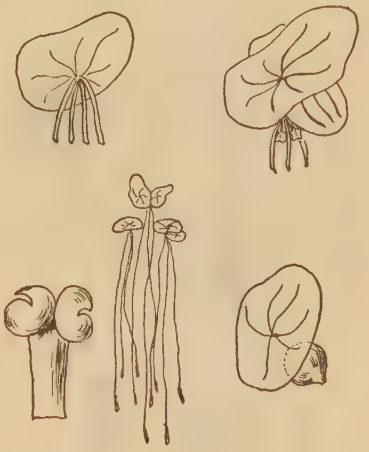

FIG. 16.—Greater duckweed (*Spirodela polyrhiza*). Found in rivers, ponds, pools, and shallow lakes, Nova Scotia to British Columbia, south to South Carolina, Texas, northern Mexico, and Nevada. Widely distributed in the Old World and tropical America. (After Britton & Brown.)

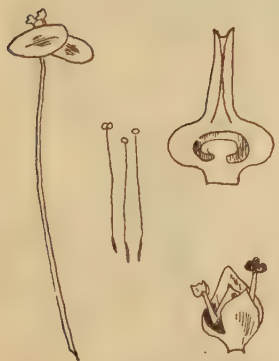

FIG. 17.—Lesser duckweed (*Lemna minor*). Found in ponds, lakes, and stagnant waters throughout North America below 58° N. lat. Also in Europe. (After Britton & Brown.)

FIG. 18.—Water clover (*Marsilea quadrifolia*). Found along the shores of Bantam Lake, Litchfield County, Conn., whence it has been introduced into various parts of the country, notably eastern Massachusetts. Native of Europe and Asia. (After Britton & Brown.)

The lotus (*Nelumbo lutea*) is troublesome to the pond culturist, having bulbs extending 3 feet into the mud and being accordingly difficult to remove when not desired. It is, however, very ornamental, good for shade, and fairly good for shelter.

Had it been possible the waterweed, the water chestnut, the fennel-leaved pondweed, the duckweeds, and the water clover would have been eradicated. In ponds maintained for angling, however, rather than for propagating purposes, these plants should not prove unde-

FIG. 19.—Large yellow pond lily (*Nymphæa advena*). Found in ponds and slow streams, New Brunswick and Nova Scotia to Rocky Mountains, south to Florida, Texas, and Utah. Called also spatterdock. (After Britton & Brown.)

FIG. 20.—Long-leaved pondweed (*Potamogeton lonchites*). Found in ponds and slow streams, New Brunswick to Washington, south to Florida and California. (After Britton & Brown.)

FIG. 21.—Water chestnut (*Trapa natans*). Naturalized in ponds, eastern Massachusetts and near Schenectady, N. Y. Native of Europe. (After Britton & Brown.)

FIG. 22.—Lotus (*Nelumbo lutea*). Found locally in Ontario and southward to Florida, west to Michigan, Indian Territory, and Louisiana. (After Britton & Brown.)

sirable except in depths of less than 4 feet; though not without due consideration of local conditions should the fennel-leaved pondweed and the water clover be introduced, owing to their dense growth at the surface even in deep water.

WYTHEVILLE, VA.

Here the pond bottoms consist of a rich loam to a depth of 12 inches, and the range in water temperature during the summer months is from 70 to 85° F. The following list of plants gives the opinion of a former superintendent as to their respective qualities and characteristics. The preceding lists have not included semiaquatic or border plants, but arrowhead (*Sagittaria longirostra*) and water plantain (*Alisma plantago-aquatica*) are given an important place among the plants at this station. A more careful investigation may lead to the conclusion that certain semiaquatic plants are equal in value to some of their exuberant companions of the deeper water.

The curled-leaved pondweed (*Potamogeton crispus*, fig. 5) is considered the most desirable plant at this station. Its roots are on

FIG. 23.—Long-beaked arrowhead (*Sagittaria longirostra*). Found in swamps and along ponds, New Jersey and Pennsylvania to Alabama. (After Britton & Brown.)

FIG. 24.—Water plantain (*Alisma plantago-aquatica*). Found in shallow water or mud throughout North America. Also in Europe and Asia. (After Britton & Brown.)

muck bottom in water up to 6 feet deep, and it throws up a slender stalk about 2 inches above the surface, on the tip of which is a small white blossom. The plant grows luxuriantly both in summer and winter and flourishes in both cold and warm water ponds. It furnishes abundant shade and protection and is a good breeding place for aquatic insects. It is also easy to control and can be removed from the ponds without injury to the fish. Its only objectionable character is that where the soil is fertile it grows more luxuriantly than is desirable.

The waterweed (*Philotria canadensis*, fig. 9) exhibits the same characters here as at the Fish Lakes station, but is more highly esteemed, being given second place.

The parrot-feather (*Myriophyllum proserpinacoides*, fig. 2), rooting in muck bottom in water up to 6 feet deep, reaches to the surface and throws up a slender stalk about 2 inches above, with a small white blossom at the tip. Because of its value as a shade for fish

and as a breeding place for aquatic life this plant is ranked third in importance at this station. It is also an excellent plant for aquaria.

The arrowhead (*Sagittaria longirostra*) is but semiaquatic, but forms a valuable shade and shelter for the young fish. It can also be removed easily and is not difficult to control. It usually roots in soft clay up to 2 feet and throws up a slender stalk with white blossoms above the surface. The leaves are killed by the first frost, and the plant branches out from the rootstocks in the spring.

The water plantain (*Alisma plantago-aquatica*) is another border plant, being found about the edges of ponds in water only 4 to 6 inches deep, its leaves floating on the surface. It is valuable for the same characters exhibited by the arrowhead.

The Chara at this station is a large form with long, slender internodes, growing in all ponds, whether they are fed by spring or creek water. It is an excellent food producer, but grows so densely that the fish can with difficulty get through it, and it is so heavy that it will not float when cut loose from the bottom. When a pond is drawn, it settles down like a blanket,

FIG. 25.—*Chara fragilis*. A common form of Chara. (After Strasburger, Noll, Schenck, & Schimper.)

FIG. 26.—Sweet-scented white water lily (*Castalia odorata*). Found in ponds and slow streams, Nova Scotia to Manitoba, south to Florida and Louisiana. (After Britton & Brown.)

entangling the young fish so that it must be picked over by hand in order to extricate them. Its objectionable characters, in fact, are so great that it is only by comparison and on negative grounds that its merits are admitted by the superintendent.

A number of years ago the ponds at Wytheville were well stocked with curled-leaved pondweed, waterweed, and limeweed, with a few water lilies (*Castalia odorata*) scattered here and there; but water lilies increased from year to year until they took complete possession of several of the ponds. They became so dense as entirely to exclude the light from the ponds, and in consequence all the sub-

merged plants, including the Chara, were killed, leaving nothing below the lily pads for the protection of the young fish. During the period when Chara was present in great abundance and was regarded as a nuisance and the lily as a desirable plant, some of the bass ponds annually yielded an average of about 25,000 young fish each, but after the lilies took the place of all other plants the annual production dwindled to less than 2,000 fish to a pond. One is therefore forced to the conclusion that the water lily is a dangerous plant, especially in ponds having soft, fertile bottoms, and that without the submerged plants successful bass culture is impossible. By contrast, Chara, with its merit of being an excellent food producer, comes into better esteem in spite of its objectionable qualities.

FIG. 27.—White water crowfoot (*Ranunculus aquatilis*). In ponds and streams, Nova Scotia to British Columbia, south to North Carolina and California. Also in Europe and Asia. (After Britton & Brown.)

NORTHVILLE, MICH.

At the Northville (Mich.) station Chara took possession of the ponds almost immediately after completion. A few other plants have obtained a foothold, but not in appreciable quantities. The ponds are devoted to the production of small-mouthed black bass, and the results have been quite successful. A former superintendent stated that he knew of no other plant than Chara so productive of fish food of the sort acceptable to the young bass, and the objectionable characters of the plant did not, in his opinion, offset its merits.

MAMMOTH SPRING, ARK.

At the Mammoth Spring (Ark.) station, established in 1905, a portion of the bottoms of three ponds is composed of a heavy muck—the remains of an old swamp bed—and in these portions there immediately sprang up Chara, Elodea, *Ranunculus aquatilis*, Ceratophyllum, Myriophyllum, and Potamogeton, the relative abundance of each being in about the order named. The entirely new ponds and those parts of the others newly excavated are of a clay and gravel mixture. It appears from the report of the first superintendent that an attempt was made the first two seasons to establish *Ranunculus aquatilis* and Elodea in these latter, but that they were crowded out by Chara, with results in all ways satisfactory. The superintendent had no preference for any particular plants.

At this station, on April 30, 1908, a pond 18,000 feet in area was stocked with 20,000 (actual count) small-mouthed black bass fry. On

June 24, eight weeks later, there were removed from this pond 6,000 fingerlings, ranging in length from 3 to 4 inches. The rapid growth and large number of fingerlings reared is attributed to the presence of exceptional quantities of small amphipod crustaceans (Gammarus), which are a valuable fish food; and the abundance of this food, although attributable to the quality of the water, seems to be dependent also upon the presence and character of the aquatic vegetation.

The present superintendent believes that of all of the plants above mentioned Myriophyllum has proved to be the most satisfactory. "Its growth is abundant and the stalk being rather tender it is easily removed from the ponds with rakes or grass hooks attached to long handles, whenever it is desired to prepare for seining operations. After a pond has been allowed to season this plant is easily reestablished by simply covering a handful of the stalks with a shovel full

FIG. 28.—Various-leaved water milfoil (*Myriophyllum heterophyllum*). Found in ponds, Ontario and New York to Florida, Texas, and Mexico. (After Britton & Brown.)

FIG. 29.—Cat-tail (*Typha latifolia*). Found in marshes throughout North America, except in extreme north. Also in Europe and Asia. (After Britton & Brown.)

of earth at intervals of from 3 to 6 feet. If this is done in the late summer or early fall, there is a fine stand of vegetation by the following spawning time in March and April." While some of the other plants are still there, he would prefer the one species only.

SAN MARCOS, TEX.

At the San Marcos (Tex.) station one of the milfoils (*Myriophyllum heterophyllum*) is preferred to all other water plants. A former superintendent stated that here some of the water lilies, Chara, and the cat-tail (*Typha latifolia*) would, if permitted, crowd out all other plants of value. He regarded frogbit (*Rhizoclonium horsfordi*), because of its exuberant growth, as the most objectionable of all the plants found in the pond. He believed water

plants essential in pond culture, but suggested that ponds be constructed with sand and gravel bottoms with the view to keeping them free of all aquatic vegetation, except in selected places where the plants were to be walled in with concrete, the walled-in portions to be filled in with earth of the richness required by the plants selected.

At the Mill Creek station of the Michigan Fish Commission for the propagation of both large-mouthed and small-mouthed black bass Chara is the principal plant, and it is quite satisfactory to the superintendent as a food producer. At one time, he asserts "the Potamogeton drove Chara out and I could not raise 100 fish where before the Chara went I could raise 1,000." [3]

RÉSUMÉ OF OBSERVATIONS.

The various estimates of the commoner plants as found at the different stations, together with the differences in condition and environment, make generalization difficult. The foregoing observations seem to show, however, first of all that the fish-cultural value of a species is chiefly a matter of the growth it attains. Its merits as food producer, shelter, and oxygenator are determined by the kind and quantity of its foliage, stems, and roots, and so likewise are its demerits, few plants being objectionable in themselves for any reason other than growth that is overabundant or overpersistent.

The growth of plants, however, being a matter of environment, depends chiefly, in the case of rooted species, upon the character of the bottom soil. Species most desirable in one locality may be obnoxious in another where by reason of the fertile soil the growth becomes dense and difficult to control. In his paper entitled "The biological relation of aquatic plants to the substratum" Dr. Raymond H. Pond [4] shows by experiment that *Vallisneria spiralis*, *Ranunculus aquatilis tricophyllus*, *Elodea canadensis*, *Myriophyllum spicatum*, *Potamogeton obtusifolius*, and *P. perfoliatus*, hence probably all rooted aquatics, are for optimum growth dependent upon their rooting in the substratum, and his conclusions are abundantly confirmed by observations in the ponds here described. It would seem, however, that his application of the fact to fish culture might be put differently. Although it is true that good soil is to be sought, it should be added that for very rich soil it is important to avoid, if possible, plants with a tendency to rankness.

The quality of the water is a factor that may entirely control the conditions of fish culture. At Cold Springs, Ga., where the water is soft, it is impossible to obtain a permanent growth of vegetation, and the ponds must accordingly be restocked from time to time. Two species of Myriophyllum are the only plants that have been successfully maintained through a season. It sometimes happens also that even with exuberant vegetation there is a dearth of animal life, and this might be ascribed to some property or deficiency of the water, just as is the abundance of certain amphipods and other crustaceans that are an important food for young fish, these forms being known to thrive and multiply best in water containing lime.

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[3] Dwight Lydell in Transactions of the American Fisheries Society for 1905, p. 193.
[4] Report U. S. Fish Commission 1903 (1905), pp. 483–526.

A further quotation from Doctor Pond, in reference to Ceratophyllum, is of interest in this connection. This nonrooted plant he shows to be dependent primarily upon the nutrient salts in solution in the water, and thus a competitor of many of the small forms of life which derive their sustenance from the same source. A pond filled with Ceratophyllum, therefore, would be expected to contain fewer of these forms and, consequently, of the forms that live upon them. From this it would seem to follow that the water best suited to Ceratophyllum would not contain sufficient food for young fish if that plant were the predominant species, and if this reasoning is correct the value of Ceratophyllum would depend upon the presence of sufficient rooted vegetation to offset the effects of competition. Such may have been the conditions at the Fish Lakes, where there were an unusually large number of species of rooted plants, above all of which, however, the superintendent believed Ceratophyllum to be the best.

No particular species of aquatic plant can be said to be always desirable. The endless interrelations of plant and animal life and physical surroundings make the problem a special one for each locality. It should be noted, however, that according to the data here presented great caution should be used as to the introduction of pondweeds, waterweed, water clover, water lilies, frogbit, and cat-tail. The last two can not be regarded as desirable in any fish-pond. Chara, indigenous at some stations, is in most cases so much in favor as a food producer that, notwithstanding its objectionable characters, it is considered the best plant for fish-cultural purposes. It should be borne in mind, however, that at the stations where this plant is a favorite the ponds are of more recent construction than at Wytheville, for instance, where Chara became especially troublesome.

The introduction of the water lily (*Castalia odorata*) into the ponds at Wytheville, with the result of apparently crowding out two other aquatic plants, and the somewhat similar experiences at San Marcos, Tex., and at Mill Creek, Mich., suggest that the partial elimination of one species by the introduction of another may at times be advantageously attempted, and that with a full knowledge of the effects of given combinations of species a desirable balance of vegetation could be maintained by this means. This question also, however, enters the broad field of plant physiology.

Heretofore some of the lower forms of vegetation, algal growths, frequently described as "frog spittle," "water moss," and "slime," have entered into pond culture only as an element of water supply, their effect upon fish life being regarded as negligible. Observations [5] of Dr. Emmeline Moore, in behalf of the United States Bureau of Fisheries, demonstrate that this view as to the value of some species of algæ is entirely erroneous, and that in the early stages of the young fishes—particularly the first two or three weeks—their food consists largely of animal life whose food during the same period consists largely of certain species of algæ. This opens a broad field of investigation. The spirogyra, so obnoxious to the fish-culturists, is not included in Doctor Moore's list of food-pro-

[5] Dr. Emmeline Moore: The Food Which is Eaten by the Food Which the Fish Eat. Paper read at the Forty-ninth Annual Meeting of the American Fisheries Society, Louisville, Ky., Oct. 10, 1919.

ducing algæ, but it has been generally recognized by fish-culturists that spirogyra is an oxygenator. Further investigation may show that all of the algæ contribute to the sustenance of young fish. The recognized food-producing value of some species of algæ suggests great possibilities in supplying food to the young fish during the first two or three weeks, and especially so at pond-culture stations like the one at Bullochville, Ga., where the water is so soft that it has been difficult to maintain an adequate amount of plant life. A definite knowledge of the relations of all of the various species of algæ to fish production is much to be desired.

METHODS OF CONTROLLING AQUATIC VEGETATION.

ELIMINATION OF UNDESIRABLE PLANTS.

Plants that are in themselves objectionable should, of course, be eliminated for all time. There is, however, no known method of eradicating the higher forms of vegetation from ponds without destroying the fish, unless it be possible first to draw off the water. When this is done, certain forms of plants die from exposure and the roots of others can be grubbed out. Cat-tails have a root stalk habit of growth. If the plants are constantly cut, the root stalks will become weaker and weaker due to the loss of the food manufacturing leaf surface. If constant cutting is persisted in, the root stalks will starve out after two seasons.

In view of their recently recognized importance as food producers, it may be assumed that, until seining operations commence, the presence of certain species of algæ will be encouraged, and that in fishponds generally the removal of algæ will not be attempted until after the young of basses or sunfishes are a month old. However, there are times and places where it is desirable to destroy the more obnoxious forms, and this may be accomplished by means of copper sulphate, according to the method of Moore and Kellerman for the disinfection of municipal water supplies.[6] This method has been successfully adapted, not only to pond culture but also to waters containing trout, as is set forth in a report of experiments at the White Sulphur Springs station of the Bureau of Fisheries.[7] The latter application of the method is of especial interest, for the reason that trout are more than ordinarily susceptible to the toxic properties of copper.

CHECKING SUPERABUNDANT OR UNDESIRED GROWTH.

To prevent superabundance of some vegetation or to make less objectionable the presence of troublesome species that can not be eradicated, it is sometimes desired to check the growth of the plants. Mr. Kellerman states, in a letter, that in water not unusually hard the waterweed (*Philotria canadensis*), Chara, and several species of Potamogeton may be considerably checked in growth by treating the

[6] Moore and Kellerman: Copper as an Algicide and Disinfectant in Water Supplies. Bulletin 76, Bureau of Plant Industry, Department of Agriculture. (See p. 12.)

[7] Marsh and Robinson: The Treatment of Fish-Cultural Waters for the Removal of Algæ. Bulletin, U. S. Bureau of Fisheries, Vol. XXXVIII, 1908 (1910), part 2, pp. 871–890.

water with copper sulphate in the proportion of 8 pounds to 1,000,000 gallons of water. In limestone regions, however, or where the water contains a large amount of organic matter, the proportion of copper must be increased, and the method is then not applicable to fish culture because a solution of the necessary strength is fatal to most fishes. It is doubtful if any fish-culturist has attempted to retard the growth of plants by this method.

It is possible to retard the growth of plants in small ponds by keeping the mud thoroughly stirred up. Submerse plants require light in order to thrive. The result is analogous to natural conditions in streams like the Potomac River during seasons of frequent heavy rains, when the water is almost constantly roily and in consequence the growth of vegetation very much less exuberant than in dry seasons, when the water is comparatively clear. In ponds where much mud is carried in and held for a considerable length of time in suspension the growth of both algæ and the higher plants is rendered practically impossible. The same variations in vegetable growth are noticeable where suction dredges have discharged their mud into streams formerly clear. This means—roiling of the waters—has been used with success in small natural ponds maintained for other purposes but is not known to have been applied to pond culture.

Experience at various pond-culture stations shows a carp to be quite efficient in checking the growth of vegetation if given access to it early in the spring before it becomes excessive. At the Fish Lakes station several carp were placed in one of the partitions of a bass pond containing *Ceratophyllum demersum*, *Philotria canadensis*, *Potamogeton pectinatus*, *Potamogeton foliosus*, *Vallisneria spiralis*, and Nymphæa. When the pond was drawn in the fall, the bottom in this partition was absolutely destitute of any kind of vegetation. The following season carp were not introduced into this pond, and the aquatic growth became as abundant as formerly. Observations at the Erwin station in one of the large ponds where a number of adult carp were confined revealed a great scarcity of aquatic growth, although similar ponds adjoining, which contained bass and other fish, were well supplied. The plants most abundant in this pond were *Philotria canadensis* and *Potamogeton crispus*.

At the Cold Spring Harbor State fish hatchery on Long Island the water supply is taken from a long, narrow pond which collects the springs in the immediate vicinity. For many years a number of carp have been confined in this supply pond for the purpose of keeping it free from vegetation, especially algæ, with very satisfactory results. In this instance it was particularly objectionable because it clogged the screens in the hatching troughs.

The introduction of carp into breeding ponds with other fish is, however, inadvisable for various reasons, the one of present concern being that carp work chiefly on the roots of plants and in mud-bottom ponds keep the water constantly roiled, a condition unfavorable to the breeding of all pond fishes with the possible exception of the crappie. It is very probable, moreover, that the roiliness of the water is itself partly responsible for the retardation of vegetable growth now credited to the presence of carp.

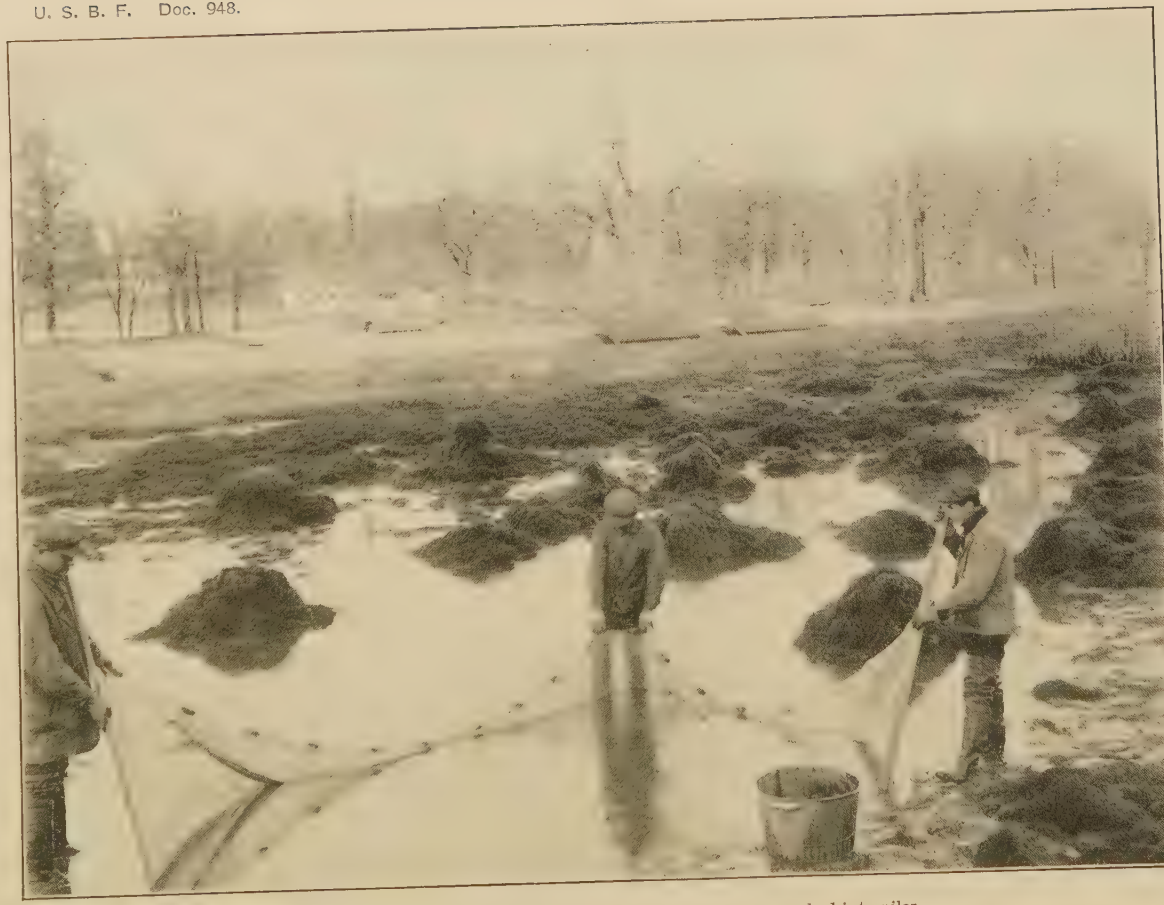

FIG. 30.—Pond after water has been drawn off and the Chara raked into piles.

REMOVAL OF VEGETATION TO PERMIT SEINING.

For the removal of vegetation in ponds preliminary to the periodical seining operations the pond culturist must depend upon mechanical methods of clearing away the foliage. It is customary to begin the removal of the young fish for distribution soon after their yolk sac is absorbed, or after the fry have been feeding but two or three weeks. At this season the growth of vegetation is not so exuberant as later in the summer, and the first crop of fish may sometimes be collected by seining around the edges of the ponds without the preliminary clearing away of the vegetation. Often, however, the shallower portions of the ponds must be cleared before even the first crop of fish can be removed. Later the fish will have sought the deeper portions, from which they can not be removed without first drawing off the water. In the latter process the foliage, if left, would settle down as the water diminished, entangling the young fish or smothering them, and it is accordingly necessary to clear away the plants before drawing off the water. The methods of removing the foliage are thus reduced to a mowing process under water, varied and adapted as conditions and circumstances may demand and ingenuity may devise. The methods and apparatus here described have been employed at pond-culture stations but are also applicable to natural ponds where the character of the bottom permits of seining operations.

At the Fish Lakes station the removal of the aquatic foliage was accomplished by mowing with ordinary scythes such as are used in a hayfield. The shallower portion of a pond was mowed first, and the water was then partially drawn off, so that it did not reach above the armpits of the mowers, its average depth being from 3 to 4 feet. The cut foliage rose to the surface and was carried to the shore in boats.

When it is desired to transfer young fish from the ponds at Northville, Mich., the slash boards are removed from the overflows and the water drawn down. As it recedes from the banks a few feet, men rake the Chara into piles, taking care that no young fish are destroyed in the operation, and continue this process until all the water and young fish are confined to the kettle of the pond. It was formerly customary to remove the vegetation by the use of teams, but experiments show that if left exposed for two weeks the Chara settles and finally disappears after the pond has been refilled. The presence of this decaying vegetation ought to stimulate the breeding of more or less insect life for young fish to feed upon.

The method of separating plants and young fish at the Mill Creek station of the Michigan Fish Commission is described by the superintendent, in substance, as follows: A space 10 feet wide around the pond is first cleared of foliage with a common iron-toothed garden rake, a piece of galvanized-wire netting of one-fourth-inch mesh being fastened to the back of it to prevent its becoming entangled in the weeds. (Any tinsmith can solder the wire cloth to the iron back.) After this has been done a homemade rake is used to remove the foliage from the deeper water of the pond. The rake is of rude construction, consisting of a cedar pole 8 feet long and 4 or 5 inches in diameter, provided with teeth 6 inches apart and 12 inches long,

made of oak or some similarly strong material. At a proper angle with the teeth are two handles about 20 inches in length, inserted as shown in Figure 31. The handles of an old plow can be utilized for the purpose. A crotch line is attached to the ends of the rake, which is operated by three men, one with waders, who stands between the handles and manipulates the implement, and two on the shore to pull it. A fourth man looks over the weeds, sorts out the fish, and pitches the growth upon the bank as it is brought ashore. When not loaded, the rake is easily floated out into the pond. To rake the bottom, the operator sometimes must put his hands and arms under water; and as he wades out with the rake he determines by the density of the moss how far it is necessary to go to secure a rakeful. Ordinarily this is about 20 feet beyond the area that was cleaned with the hand raking, but farther if the weeds are not thick. The rake is moved through the weeds slowly to allow the fish to escape, but on reaching the open space made by the garden rake it can be moved more rapidly, so that as it comes ashore, with water rushing around either end, any fish that may be ahead of it will usually escape into the pond. The few that may become entangled are

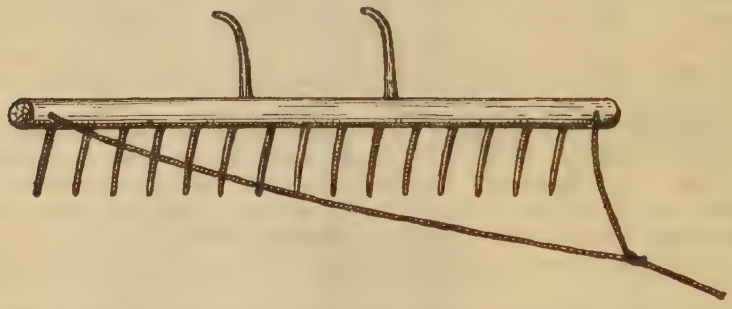

FIG. 31.—Rake devised by Dwight Lydell, and in use for removing vegetation at the Mill Creek station of the Michigan Fish Commission. (For description see text.)

released by swift handling of the weeds as they are brought ashore. After the first raking is completed a seine is used to remove all fish that may be in the cleared space. Then the rake is used again farther out in the pond, the process being repeated until the pond has been thoroughly cleared of vegetation or the desired number of fish have been obtained.

At the Wytheville station a boat is employed in the removal of the aquatic vegetation from portions of the pond where the growth is most dense. Fastened to each end of the boat is a cleat, through which is a hole about 2 inches in diameter, or of sufficient size to hold a stake loosely fitted in it, the stakes being driven into the bottom of the pond for the purpose of holding the boat steady while the vegetation is being pulled by the rakes. The loosened mass is then loaded into the boat. After the pond bottom has been gone over in this manner the sluices are opened, and men following the water as the pond is drawn pull by hand the remaining vegetation and stack it in piles. If any patches of Chara are found where the fish are apt to lodge, these are reached with rakes and thinned to release the fish. After the fish have been removed and while the pond bot-

tom is still wet the piles of Chara are removed to the shore with pitchforks. In the removal of such plants as water lilies, rushes, cat-tails, etc., the ordinary scythe is used, but this method is resorted to as little as possible because of the tracks made in the bottom of the pond and the muddying of the water.

At the Mammoth Spring station the method of drawing ponds and removing vegetation is somewhat similar to that pursued at Northville. If it is desired to remove fish less than 2 inches in length, all of the vegetation is raked out upon a raft and poled to the bank for subsequent removal by horse and wagon. If larger fingerlings are in the pond, the vegetation is first cleared as thoroughly as possible by a similar method from a space about 100 feet in diameter around the outlet drain. A channel is then cleared from the outlet of the pond to its inlet. Ordinarily this preliminary work requires the services of two men to each pond for two days. The ponds range from three-fourths to 1¼ acres in area. On the third day the water is drawn down to the cleared space near the outlet. As it recedes the Chara is raked into windrows, the men working in from 1 to 2 feet of water, thus keeping a clear channel ahead of the water line. Windrows are preferred to stacks, because the fish have a means of retreat through the channel formed between the rows.

Four or five men are engaged in the work at pond-drawing time. Perhaps by 3 p. m. of the third day the water will have been drawn down to the "kettle," the 100-foot cleared pool. If the pond contains adult fish, they are at this time removed by sweeping a coarse-meshed seine through the pool. The following morning the water temperature and other conditions are favorable for the removal of the fingerling stock.

A raft is preferred to a boat, because it will carry a large load of vegetation and the water quickly drains from it. It is homemade, 12 by 16 feet. The outer framework of 2 by 12 inch planks is fastened together by 6-inch bolts and then the inner planks are slipped into place. The raft is supported by six 10-gallon iron-bound kegs wired to the framework. The round holes in the center of each end plank are for the insertion of stakes to hold the raft in place while loading.

The claim of superiority of a raft over the boat ordinarily used for the same purpose seems well founded and leads to the suggestion that a shallow scow of dimensions to suit conditions, with deck and side rails, would also allow the water to drain off as the deck is loaded with vegetation and would be more easily handled. Rapid movement in the comparatively small ponds of the fish-culturist not being essential, trucks might be attached to the bottom of the scow for convenience in drawing it ashore or from one pond to another.

At the San Marcos station the removal of aquatic vegetation is accomplished with an ordinary scythe, the men going into the water and cutting the growth as closely as possible. For cutting the heavier vegetation at a distance from the embankments a scythe is sometimes attached to a piece of three-quarter-inch iron piping from 10 to 30 feet in length, the latter being spread at the end to hold the shank of the scythe, which is riveted to it with two small bolts. Hand rakes, especially made from 4-tined hayforks, are then used, care being taken to examine each rakeful of foliage for young fish. An espe-

cially made iron rake shown in Figure 32 has also proved a very effective implement. The main bar, 3 inches in diameter and 8 feet long, is set with 15 teeth 15 inches long and forms the diagonal of a square frame, at the two remaining corners of which is fixed an iron ring. With a strong rope through each ring, the rake is drawn from one side of the pond to the other, making an 8-foot swath. Two men are usually required on each side of the pond to manipulate the rake.

At the Cold Springs (Ga.) station there is but one pond in which vegetation (Myriophyllum) is sufficiently dense to necessitate its removal prior to seining for the young fish. In this pond it grows

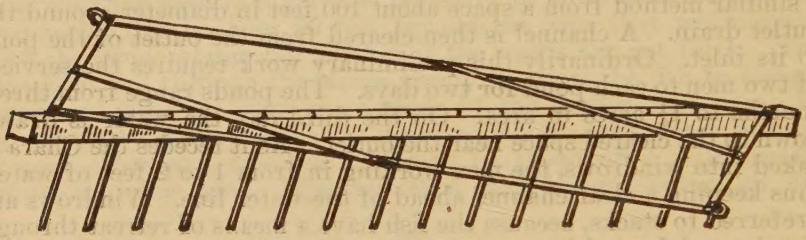

FIG. 32.—Iron rake in use at San Marcos (Tex.) station. (For description see text.)

exuberantly from bottom to surface and is removed by the use of a wire, about the size of a telegraph wire, loaded with weights and pulled through the pond much as a seine is hauled, except that it is jerked vigorously from side to side. In this way the tender growth of the Myriophyllum is easily severed. It is then dragged ashore with a long rake similar to the one in use at San Marcos.

Owing to the necessity for periodically removing the aquatic foliage at pond-culture stations and the expense involved in the present methods of performing this task, it is obvious that here also is a field for experimentation, but that in this, as in other efforts of the fish-culturist to effect economies, each station has its own problems.